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Comparison of left ventricular manual versus automated derived longitudinal strain: implications for clinical practice and research

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Abstract Systolic global longitudinal strain (GLS) is emerging as a useful metric of ventricular function in heart failure and usually assessed using post-processing software. The purpose of this study was to investigate whether longitudinal strain (LS) derived using manual-tracings of ventricular lengths (manual-LS) can be reliable and time efficient when compared to LS obtained by post-processing software (software-LS). Apical 4-chamber view images were retrospectively examined in 50 healthy controls, 100 patients with dilated cardiomyopathy (DCM), and 100 with hypertrophic cardiomyopathy (HCM). We measured endocardial and mid-wall manual-LS and software-LS, using peak of average regional curve [software-LS(a)] and global ventricular lengths [software-LS(l)] according to definition of Lagragian strain. We compared manual-LS and software-LS by using Bland–Altman plot and coefficient of variation (COV). In addition, test–retest was also performed for further assessment of variability in measurements. While manual-LS was obtained in all subjects, software-LS could be obtained in 238 subjects (95 %). The time spent for obtaining manual-LS was significantly shorter than for the software-LS (94 ± 39 s vs. 141 ± 79 s, $P < 0.001$). Overall, manual-LS had an excellent correlation with both software-LS (a) ($R^2 = 0.93$, $P < 0.001$) and software-LS(l) ($R^2 = 0.84$, $P < 0.001$). The bias (95 %CI) between endocardial manual-LS and software-LS(a) was 0.4 % [−2.8, 3.6 %] in absolute and 3.5 % [−17.0, 24.0 %] in relative difference while it was 0.4 % [−2.5, 3.3 %] and 3.4 % [−16.2, 23.1 %], respectively with software-LS(l). Mid-wall manual-LS and mid-wall software-LS(a) also had good agreement [a bias (95 % CI) for absolute value of 0.1 % [−2.1, 2.5 %] in HCM, and 0.2 % [−2.2, 2.6 %] in controls]. The COV for manual and software derived LS were below 6 %. Test–retest showed good variability for both methods (COVs were 5.8 and 4.7 for endocardial and mid-wall manual-LS, and 4.6 and 4.9 for endocardial and mid-wall software-LS(a), respectively. Manual-LS appears to be as reproducible as software-LS; this may be of value especially when global strain is the metric of interest.

Keywords Echocardiography · Strain imaging · Global longitudinal strain · Post-processing software · Vendor-independent · Ventricular function · Heart failure · Hypertrophic cardiomyopathy · Dilated cardiomyopathy

Abbreviations

COV	Coefficient of variation
DCM	Dilated cardiomyopathy
EF	Ejection fraction
HCM	Hypertrophic cardiomyopathy
LS	Longitudinal strain
LV	Left ventricular
LVEDV	Left ventricular end-diastolic volume
LVESV	Left ventricular end-systolic volume

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Introduction

Left ventricular (LV) deformation analysis was first described in the 1970s [1] and the field of strain imaging has gathered significant interest because of its diagnostic and prognostic value [2]. Speckle tracking is currently the most commonly used method for ventricular strain analysis. Compared to tissue Doppler based techniques, it has the advantage of not being angle dependent although it requires optimal image resolution for analysis [3]. Using speckle tracking, strain is derived as $(L_1 - L_0)/L_0$ where L_1 is the post-deformation length and L_0 is the original length of an object [3]. This refers to the concept of Lagrangian strain where L_0 remains constant throughout strain analysis; in contrast tissue Doppler imaging measures natural strain where L_0 varies through the analysis cycle [3]. By definition, systolic Lagrangian strain can also be obtained by manual tracings of LV length at end-diastole (L_0) and end-systole (L_1). If proven reproducible without having systematic bias, this could provide an alternative method for global strain measurements or an additional quality control step during post-processing analysis. This may be particularly relevant as recent studies have also highlighted some inter-vendor variability in speckle derived strain values [2, 4–6].

In this study, we sought to determine whether longitudinal strain derived using manual tracings of end-diastolic and end-systolic lengths (manual-LS) would be reliable and time efficient, when compared to longitudinal strain derived from a vendor independent post-processing software (software-LS). In this study, we focused on LS as this has been previously proven to be the most feasible and reliable measure of ventricular strain [7] in addition to having strong prognostic value [8, 9]. In the first part of the study, we focused on endocardial strain and in the second part of the study, we focused on mid-wall ventricular strain measures. Mid-wall strain assessment may be particularly important in patients with ventricular hypertrophy as previous studies have shown that mid-wall rather than endocardial dynamics better reflect ventricular dysfunction [10, 11].

Methods

Study population

Overall, 250 subjects randomly selected from Stanford inherited cardiomyopathy and healthy aging databases; these included 50 healthy subjects, 100 patients with a diagnosis of asymmetric hypertrophic cardiomyopathy (HCM) and 100 patients with dilated cardiomyopathy (DCM). For comparative purposes, the three groups were age and sex matched during the selection process. We excluded patients who were in atrial fibrillation or other irregular rhythm at the time of the study. The diagnosis of asymmetrical HCM was based on echocardiographic findings of a septal thickness >13 mm and septal-to-posterior wall thickness ratio >1.3, in the absence of any other cause that could account for the degree of hypertrophy [12]. From the Stanford cardiomyopathy database, patients with DCM were selected in the presence of an LV ejection fraction (EF) <45 % and in the absence of hemodynamically significant coronary artery disease or prior myocardial infarction.

Echocardiography

All echocardiographic studies were performed using commercially available echo systems (Sonos 7500, iE33, and EPIQ 7C; Philips Medical Imaging, Eindhoven, the Netherlands). Standard measurements of ventricular wall thickness and dimensions as well as EF were performed according to the guidelines of the ASE recommendations [13]. LVEF was calculated using modified Simpson method and represents an average of three measures. Foreshortening in the apical 4-chamber view was noted if the endocardial border of the apex was significantly displaced in systole. In fact, Rogers et al. [14] have previously shown using magnetic resonance imaging that the endocardial border of the apex usually only displaces minimally during systole (about 1.5 mm); this small apical displacement is due to the opposite effects of the apical anterior motion and myocardial thickening.

Strain analysis with post processing software

Post-processing strain analysis was performed using a vendor independent commercially available dedicated software, Image-Arena™ (TOMTEC Imaging System, Unterschleisheim, Germany). Using this software, ventricular strain could be measured using three metrics: (A) global longitudinal strain value (software-LS(l); Fig. 1A), which is calculated by using the entire myocardial length while computing the deformation, (B) peak strain value of averaged regional strain curve (software-LS(s); Fig. 1B), which is obtained by averaging the segmental strain curves and (C) averaged peak regional stain values (Fig. 1C), which is derived from averaging the peak strain values of all segment. Most studies mainly focus on either software-LS(l) or software-LS(a) when referencing GLS measures [3]; we, therefore, focused on these two measures in the current study. The endocardial border was traced manually in apical 4-chamber view at end-diastole and the software automatically tracked the ventricular wall on subsequent frames in a selected beat. Adequate tracking was verified and corrected by adjusting the region of interest or the contour. The software automatically divided LV wall into six segments and

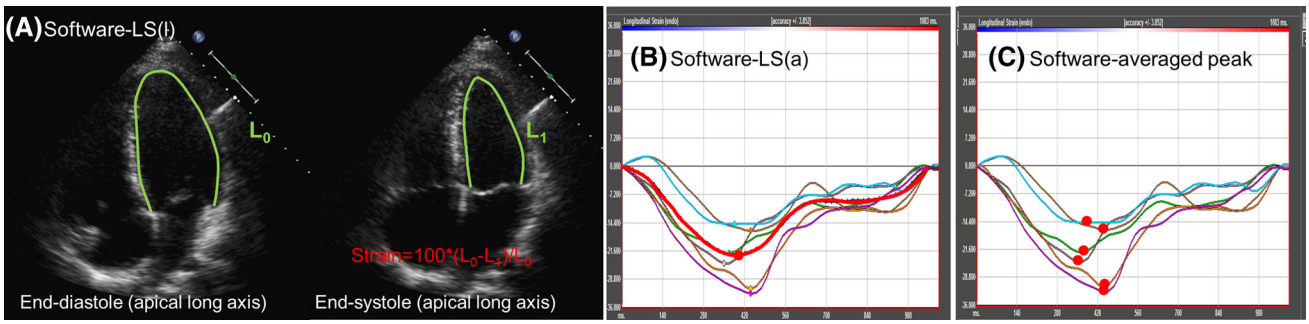

Fig. 1 Lagrangian strain can be derived using three different methods, i.e. derived from length as the manual method does, using the peak of the average curve (derived from each region of interest) or the average from each peak. (**A**) The concept of "longitudinal strain (LS)" derived using end-diastolic and end-systolic length; L_0 is the LV length in end-diastole and L_1 is that in end-systole. software-LS(l) is calculated by the formula; $100 \times (L_1 - L_0)/L_0$. In (**B**), the *red curve* is the average curve of six curves. The peak value of this curve is the "peak of average curve [software-LS(a)]". In the (**C**), the *red dots* are the peaks of six curves. The "average of each peak" is the average of these six values. The average of each peak is not routinely obtained in clinical practice

their strain curves were obtained (Fig. 1). Software-LS(l) and software-LS(a) (Fig. 1A, B) were analyzed. The time to obtain the strain values after image loading was also registered (software-time), which included first tracing, the software computation time, and adjusting of the tracking. These measures were done by experienced cardiologists who had already performed more than 500 strain curve analysis.

In addition to the verification of the tracking, the difference of LVEF derived from the software and the Simpson method was used as quality control. If the difference was more than 5 %, tracking was re-verified. If significant deviation of contour from endocardium was still observed the analysis was discontinued.

Manual longitudinal strain analysis

Manual-LS was calculated from apical 4-chamber view using the Xcelera work station. The endocardial borders in end-diastole and end-systole [3] were traced manually from the septal to the lateral mitral annulus points, excluding trabeculations and the papillary muscle from the cavity. Initial length (L_0) was obtained in end-diastole and final length (L_1) in end-systole. Manual-LS was calculated as the formula; manual-LS $(\%) = 100 \times (L_1 - L_0)/L_0$ [1]. The time to obtain both lengths was also registered (manual-time). For quality control, the apical reference point was kept relatively stable [14] to avoid the overestimation of strain measures secondary to apical foreshortening. Moreover, we traced the mitral annular plane for better delineation of the base (Fig. 2).

Mid-wall strain assessment (manual-LS and software-LS)

For mid-wall manual-LS, ventricular mid-wall length was traced in both end-diastole and end-systole to obtain L_0 and L_1 as same as endocardium. Mid-wall region was defined as the mid-point between the epicardial and endocardial borders (Fig. 2). Mid-wall software-LS(a) was also evaluated in subjects who showed significant difference between endocardial and mid-wall LS by manual method. Although this is an off-label use of the Image-Arena^{TM} software, mid-wall instead of endocardium was traced manually in apical 4-chamber view in end-diastole and the software automatically tracked the line and the strain curves were obtained.

Intra- and interobserver variability using same image and test–retest testing

For intraobserver variability, 20 healthy controls, 30 patients with HCM, and 30 patients with DCM were randomly selected and their data were reanalyzed by the same investigator two to four weeks after the first analysis without references to the initial tracings. For interobserver variability, the same subjects were reanalyzed by the other investigator. Intra- and interobserver variability in manual-LS and software-LS was assessed using the Bland–Altman analysis [15] and coefficient of variation (COV). The absolute bias was calculated as the mean difference between the repeated values. The COV was calculated as standard deviation divided by the mean. All initial measurements were blinded to the investigators. In addition, for further assessment of variability of software-LS and Manual-LS, test–retest was performed in 21 patients with heart failure and four healthy subjects. Two sonographers acquired two images of apical 4-chamber view in each subject and COV was calculated for evaluating variability of endocardial and mid-wall Software-LS or Manual-LS.

Statistical analysis

Variables are presented as counts and percentages or mean and standard deviation. Categorical variables were compared

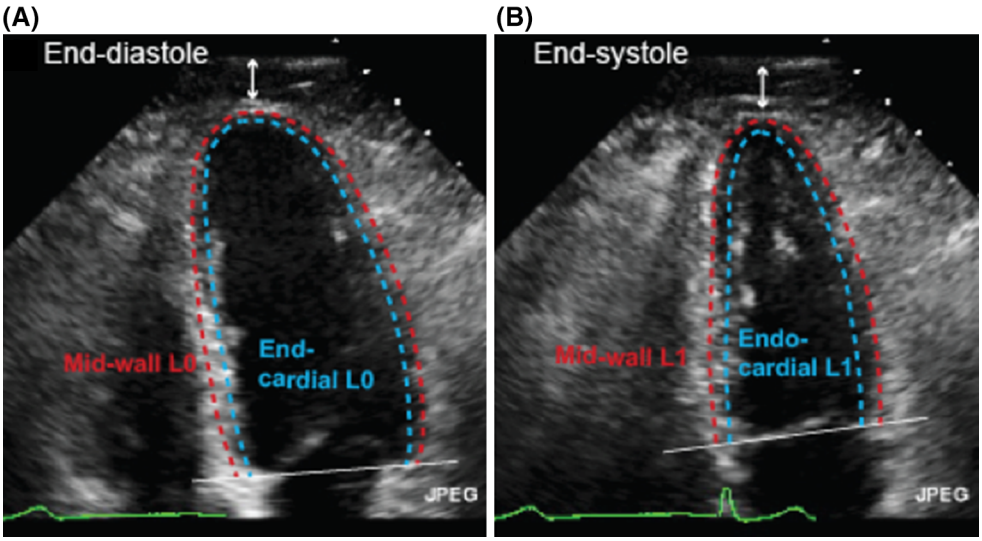

Fig. 2 Longitudinal strain derived using manual tracings. The *blue dotted line* shows the endocardial and the *red dotted line* shows the mid-wall tracing. The *white lines* show the annular planes used as reference. Apical reference point is shown as the *white arrows* and the distance of white two-headed *arrows* were measured and used for evaluating systolic apical foreshortening

using Pearson's Chi-square test or Fisher's exact test, as appropriate. Two sets of data with normal distribution were compared with paired Student *t* test or Wilcoxon signed-rank test, as appropriate. The agreement between manual-LS and software-LS were tested by Bland–Altman analysis [15] and Lin's concordance correlation coefficient, which quantifies the agreement between the two measures (i.e., manual tracing and software analysis). The absolute bias or difference was calculated as the mean difference between the values of manual-LS and software-LS and was plotted against the average value of them. The relative bias or difference was calculated by taking the percentage of the difference between the values of manual-LS and software-LS. Outlier is defined as the difference between the values of manual-LS and software-LS >2 % in absolute difference or >15 % in relative difference. We chose these cut-off values because these values correspond approximately two standard deviation of absolute and relative differences in our study. Linear regression analyses were also performed to analyze the relationship of the values between manual-LS and software-LS. A two-sided *P* value of <0.05 was considered significant. All analyses were performed using SPSS 21 software® (SPSS Inc, Chicago, Illinois).

Results

Baseline characteristics are shown in Table 1. By design, there was no significant difference in age and sex among the three groups. All subjects were in sinus rhythm at the time of echocardiographic evaluation. Endocardial manual-LS and software-LS were smaller in absolute value patients with DCM or HCM compared with healthy subjects in our cohort.

Comparison between manual versus software derived endocardial LS measures

Manual-LS was obtained in all subjects (100 %), while software-LS was feasible in 238 subjects (95 %). The software adequately tracked the left ventricle in 49 healthy controls (98 %), 90 patients (90 %) with HCM, and 99 patients with DCM (99 %), (Fig. 3A). Acquisition time was statistically significantly shorter with manual tracing when compared to using the software (94 ± 39 vs. 141 ± 79 s, $P < 0.001$). Using manual tracing, acquisition time was longer for DCM (115 ± 45 vs. 87 ± 28 s, $P < 0.001$); in contrast, using software method, acquisition time was longer for HCM (165 ± 77 vs. 117 ± 72 s, $P = 0.015$) (Fig. 3B).

Overall there was good concordance between manual and software derived methods. Using Bland–Altman analysis (Fig. 4), the absolute and relative bias for software-LS(a) were 0.4 % (95 % CI −2.8 to 3.6 %) and 3.5 % (95 % CI −17.0 to 24.0 %) and for software-LS(l), 0.4 % (95 % CI −2.5 to 3.3 %) and 3.4 % (95 % CI −16.2 to 23.1 %), respectively. The coefficient of determination were excellent with both software-LS(a) ($R^2 = 0.93$, $P < 0.001$) and software-LS(l) ($R^2 = 0.84$, $P < 0.001$) as were Lin's concordance correlation coefficient, Rc = 0.94 (95 % CI 0.92–0.95) between software-LS(a), Rc = 0.92 (95 % CI 0.90–0.93) between software-LS(l).

Table 1 Baseline characteristics of the study population

	Healthy (n = 50)	DCM (n = 100)	HCM (n = 100)	Overall *P* value
Age (years)	51.0 ± 11.8	48.5 ± 12.9	51.0 ± 14.1	0.32
Male, n (%)	29 (58)	69 (69)	57 (57)	0.18
Body surface area (m^2)	1.9 ± 0.2	2.0 ± 0.3*	2.0 ± 0.3*	0.003
HR (bpm)	64.1 ± 9.4	72.7 ± 12.3*	73.2 ± 13.7*	<0.001
Systolic BP (mmHg)	123.5 ± 12.9	100.7 ± 23.9*	121.5 ± 17.1$^{\#}$	<0.001
Diastolic BP (mmHg)	75.5 ± 8.8	43.4 ± 34.5*	73.1 ± 11.2$^{\#}$	0.001
LVEDV (ml)	101.1 ± 23.5	256.1 ± 131.8*	89.3 ± 29.8*$^{\#}$	<0.001
LVESV (ml)	38.1 ± 10.3	191.2 ± 114.6*	29.6 ± 13.2*$^{\#}$	<0.001
LVEF (%)	62.4 ± 4.7	27.6 ± 9.1*	67.6 ± 6.4*$^{\#}$	<0.001
LS (endocardial) (%)	−20.8 ± 1.5	−12.2 ± 5.2*	−18.7 ± 3.5*$^{\#}$	<0.001
LS (mid-wall) (%)	−19.6 ± 1.4	−12.2 ± 2.3*	−15.7 ± 2.3*$^{\#}$	<0.001

HCM hypertrophic cardiomyopathy, *DCM* dilated cardiomyopathy, *HR* heart rate, *BP* blood pressure, *LVEDV* left ventricular end-diastolic volume, *LVESV* left ventricular end-systolic volume, *LVEF* left ventricular ejection fraction, *LS* longitudinal strain. The longitudinal strain values presented in this table were measured using the manual tracing method

* $P < 0.05$ versus healthy; $^{\#}$ $P < 0.05$ versus DCM

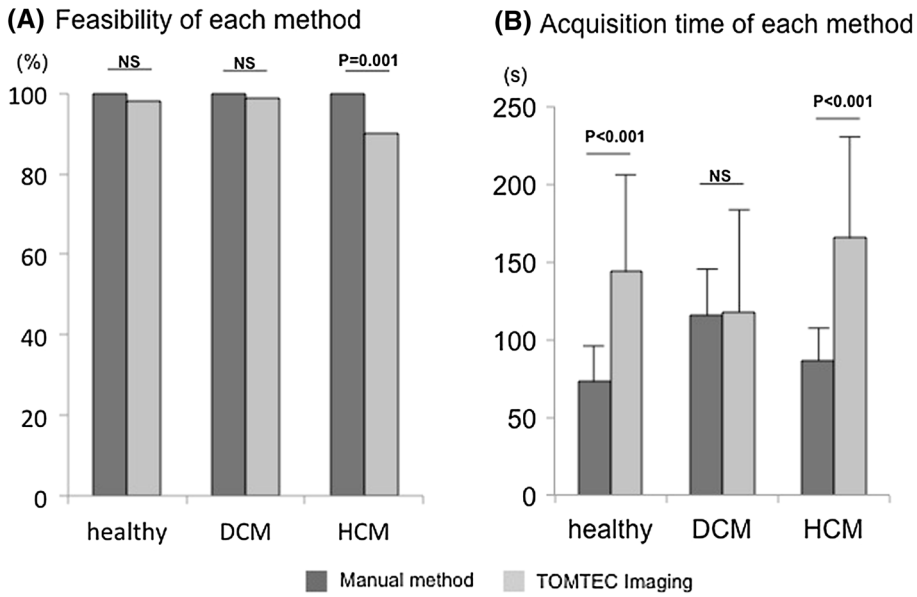

Fig. 3 Feasibility and acquisition time of the two methods in each group. **A** The result of the feasibility of the two methods. While the feasibility of the two methods was comparable in the control group and the DCM group, the feasibility of the manual-LS was better in the HCM group. **B** The result of time acquisition, which does not include the image loading time in the software assessment

According to etiology, there was a non-significant difference in relative bias values between DCM and HCM, i.e. 5.3 % [−14.2, 24.9 %] versus 2.4 % [−21.4, 26.1 %], $P = 0.34$. Overall, there was a better association between manual and software derived LS in DCM ($R^2 = 0.98$) than in HCM ($R^2 = 0.67$, $P < 0.001$). The association in HCM was better if no foreshortening was observed ($R^2 = 0.78$, $P < 0.001$), while a moderate correlation in those with foreshortening ($R^2 = 0.45$, $P < 0.001$). There was a lower coefficient of determination in the healthy controls ($R^2 = 0.36$, $P < 0.001$) but the range of strain values was smaller and the sample size was smaller.

Analysis of outlier cases between manual-LS and software-LS

Outlier cases were not commonly observed in our cohort, i.e. 28 cases (15 %) for absolute values >2 % and 27 cases

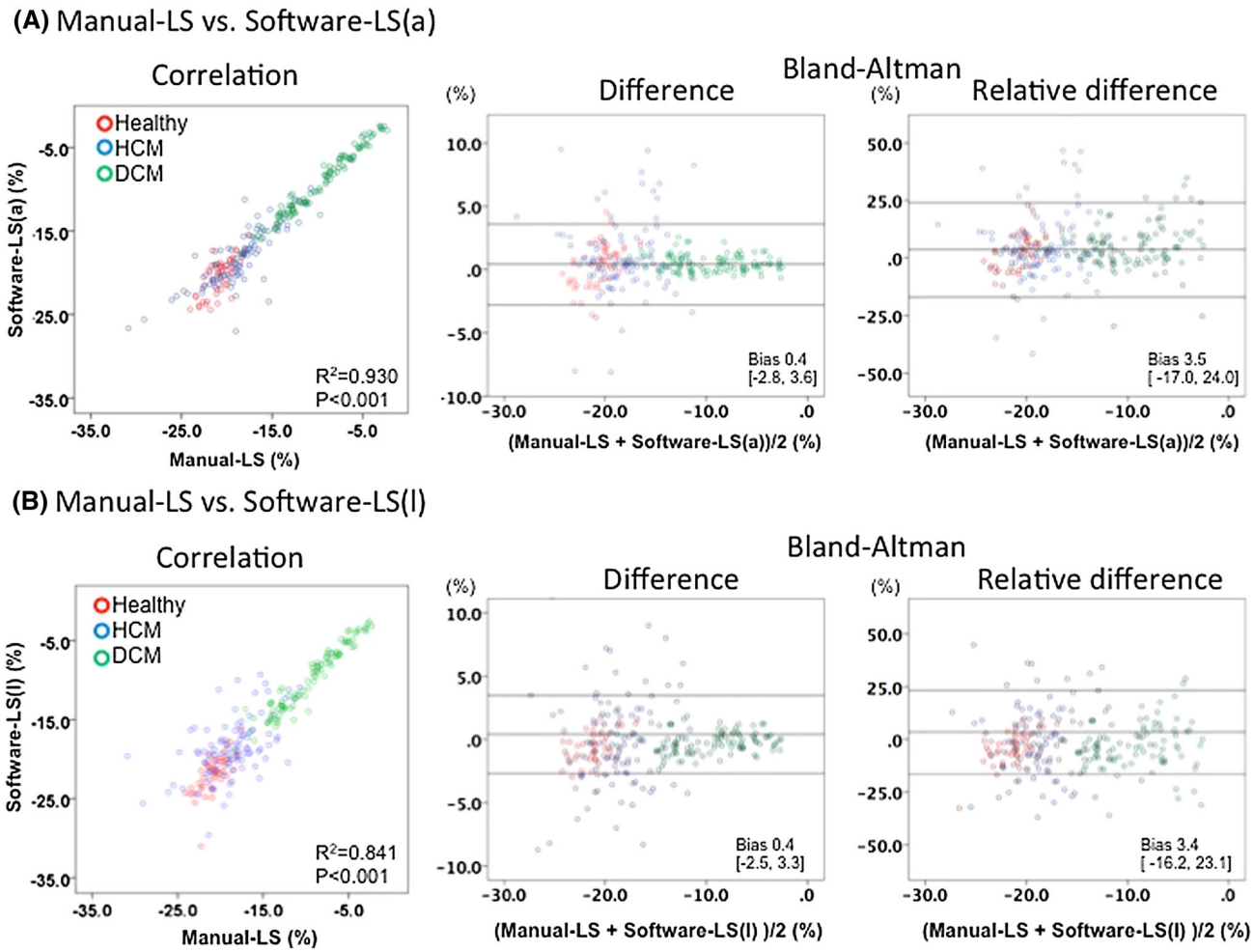

Fig. 4 Comparison of longitudinal strain measures using manually versus software derived values. The values of manual-LS had a good linear correlation with those from the software assessment of both software-LS(a) (**A**) and software-LS(l) (**B**). There was also very minimal systematic bias associated with the two techniques

Table 2 Factors potentially contributing to differences between manual versus software derived longitudinal strain values in patients with heart failure

	Absolute difference <2 % n = 160	Absolute difference >2 % n = 28	*P* value
HCM, n (%)	65 (41)	25 (89)	<0.001
DCM, n (%)	95 (59)	3 (11)	
Apical foreshortening, n (%)	3 (2)	9 (32)	<0.001
	Relative difference <15 % n = 161	Relative difference >15 % n = 27	*P* value
HCM, n (%)	79 (49)	11 (41)	0.34
DCM, n (%)	82 (51)	16 (59)	
Apical foreshortening, n (%)	6 (4)	6 (22)	<0.001

HCM hypertrophic cardiomyopathy, *DCM* dilated cardiomyopathy, *LS* longitudinal strain

(14 %) for relative values >15 % (Table 2). Only foreshortening was significantly associated with outlier absolute and relative differences. HCM etiology was associated with absolute differences >2 % but not with relative differences >15 %.

Comparison of mid-wall manual-LS and software-LS

Mid-wall manual-LS was significantly lower in absolute value than endocardial manual-LS in the healthy controls and in patients with HCM (−19.6 ± 1.4 vs. −20.8 ± 1.5 %,

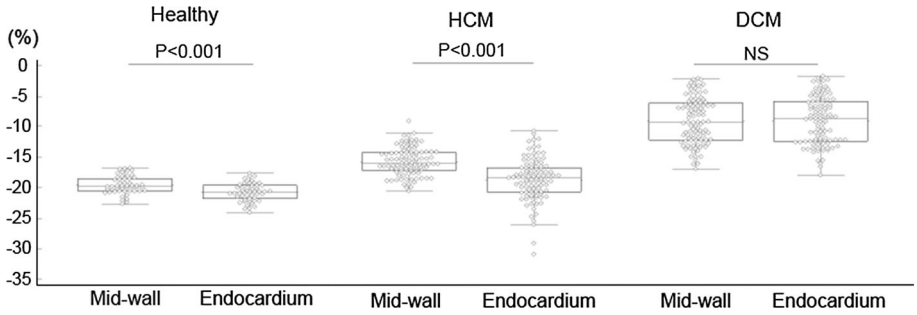

Fig. 5 Comparison of endocardial and mid-wall manual longitudinal strain measurements. There was a significant difference between endocardial and mid-wall manual-LS in patients with HCM and healthy controls, whereas no significant difference in patients with DCM

$P < 0.001$ for healthy group and -15.7 ± 2.3 vs. -18.7 ± 3.5 %, $P < 0.001$ for patients with HCM), whereas these values were not statistically different in patients with DCM (-9.5 ± 3.8 vs. -9.6 ± 3.9 %, $P = 0.45$) (Fig. 5). Between the two groups, the ratio of endocardial to mid-wall manual-LS value was significantly higher in patients with HCM than in healthy controls (endocardial/mid-wall software-LS(a); 1.20 ± 0.22 for HCM and 1.06 ± 0.08 for healthy controls, $P < 0.001$).

For the comparison between manual-LS and software-LS, we focused on healthy controls and patients with HCM as our values of manual-LS showed differences only in these groups. The software adequately tracked LV mid-wall 81 % in patients with HCM and 88 % in healthy controls. Mid-wall manual-LS and software-LS showed good agreement [a bias was 0.1 % [−2.1, 2.5 %] and COV was 3.6 in patients with HCM, and bias was 0.2 % [−2.2, 2.6] and COV was 3.1 in controls]. For Lin's concordance correlation coefficient, Rc = 0.91 (95 % CI 0.88–0.94).

Receiver-operator-characteristic (ROC) curve analysis for functional discrimination of patients with HCM from healthy controls showed the AUC = 0.74, ($P < 0.001$) for endocardial manual-LS values and an AUC = 0.93 ($P < 0.001$) for mid-wall LS values. The AUC values were statistically different from each other ($P < 0.001$). When using software derived strain values, similarly mid-wall dynamic better discriminated the patients: AUC = 0.72, ($P < 0.001$) for endocardial software-LS values and, AUC = 0.90 ($P < 0.001$) for mid-wall software-LS values. The AUC values were also statistically different from each other ($P < 0.001$).

Intra- and interobserver variability and coefficients of variation

Table 3 summarizes the intra- and interobserver variability in strain measures. All COVs in the table were below 6 % with no clear difference between manual and software related values. For test–retest, COVs between values were 5.8 for endocardial manual-LS, 4.6 for endocardial software-LS, 4.7 for mid-wall manual-LS, and 4.9 for mid-wall software-LS.

Discussion

The main finding of our study is that deriving longitudinal strain measures using manual tracing of ventricular lengths is reproducible. In addition, no systematic bias was observed when compared to vendor independent software derived longitudinal strain.

In recent years, longitudinal ventricular strain has emerged as a very valuable metric for the evaluation of patients with cardiovascular disease [2, 16, 17]. This was first highlighted in a landmark study by Dumesnil et al. [1] in the late 1970s where they described the relationship between LV longitudinal and circumferential fiber shortening. To facilitate the assessment of global and regional ventricular strain, several vendors have developed automated strain analysis software. One of the drawbacks of automated analysis software, however, is that they require high spatial and temporal resolution for reliable tracking. Moreover, variability among vendors may limit direct comparison between studies [18, 19]. The recent study of Nagata et al. [4] represents one of the most comprehensive inter-vendor comparison study. Despite moderate associations, the study highlights the large limits of agreement between vendor post-processing software [13]. Moreover, to date vendor-independent software have only been validated for endocardial or epicardial strain measures, the latter often being difficult to track using automated methods [20].

The key message of our study is that deriving LS measured using manual tracing of ventricular lengths is feasible in addition to having excellent intra and inter-observer reproducibility and favorable test–retest characteristics. More importantly, no systemic bias between methodologies was observed in our study and both software derived LS based on length or average strain values had comparable limits of agreement with the manual method. In contrast to previous studies, we focused not only on healthy subjects but also included patients with DCM or HCM allowing methodological comparison across a wide range of strain values and different ventricular morphology. Our study also provides some insights that can be valuable for quality control. In fact, we found that foreshortening is an important cause of outlier cases

Table 3 Intra- and interobserver variability

	Mean ± SD	R^2	Bias ± SD	95 % LOA	COV
Intraobserver variability (n = 80)					
Simpson LVEF (%)	46.9 ± 21.7	0.97	−0.1 ± 3.6	−7.2 to 7.1	3.3
Endocardial manual-LS (%)	−16.1 ± 6.1	0.96	−0.4 ± 1.8	−3.91 to 3.19	3.7
Endocardial software-LS-average (%)	−15.7 ± 5.2	0.97	0.1 ± 1.5	−2.96 to 3.13	3.4
Mid-wall manual-LS (%)	−14.5 ± 5.3	0.98	0.0 ± 0.9	−0.18 to 0.20	2.2
Mid-wall software-LS-average[a] (%)	−17.9 ± 2.4	0.86	−0.1 ± 1.3	−2.7 to 2.5	4.0
Interobserver variability (n = 80)					
Simpson LVEF (%)	47.2 ± 20.7	0.89	0.1 ± 6.5	−12.9 to 13.1	5.7
Endocardial manual-LS (%)	−15.8 ± 5.7	0.92	0.3 ± 2.4	−4.44 to 5.12	5.7
Endocardial software-LS-average (%)	−15.5 ± 5.9	0.95	0.4 ± 1.9	−3.40 to 4.25	4.8
Mid-wall manual-LS (%)	−14.6 ± 5.1	0.96	0.2 ± 1.5	−2.74 to 3.10	4.7
Mid-wall software-LS-average[a] (%)	−17.8 ± 2.5	0.83	0.1 ± 1.6	−3.30 to 3.10	4.5
Test retest (n = 25)					
Endocardial manual-LS (%)	−15.1 ± 4.2	0.78	−0.2 ± 2.1	−5.31 to 3.94	5.8
Endocardial software-LS-average (%)	−14.6 ± 5.0	0.88	−0.0 ± 1.8	−3.62 to 3.59	4.6
Mid-wall manual-LS (%)	−13.4 ± 3.9	0.85	−0.2 ± 1.6	−3.36 to 2.94	4.7
Mid-wall software-LS-average[a] (%)	−12.8 ± 4.9	0.87	−0.1 ± 1.9	−2.20 to 3.67	4.9

Bias Difference between paired measurements, *SD* standard deviation, *LOA* limits of agreement (of difference), *COV* coefficient of variation, *LS* longitudinal strain. Of importance the analysis were performed on independent frames without prior knowledge of the frames chosen previously

[a] Data for patients with HCM and healthy controls. The coefficient of determination for the test–retest was not performed on the same sample size as for the intra and interobserver variability and direct comparison should be avoided

between software and post-processing values. Using manual tracing, adjustment for foreshortening can be partially accomplished and would minimize overestimation of strain values [14]. The fact the healthy had lower coefficient of determination is not surprising as the sample size was smaller and the range of strain values much narrower than in pathological cases.

Another important contribution of our study is that we also found good agreement for mid-wall strain measurements. As expected based on ventricular geometry, the ratio of endocardial to mid-wall LS was significantly higher in patients with HCM as compared to healthy controls and patients with DCM. The fact that mid-wall LS allowed better functional discrimination than endocardial LS in patients with HCM may suggest its greater value but this needs further investigation in larger cohorts. The better discrimination of mid-wall strain values is consistent with recent reports that have shown that mid-wall LVEF or mid-wall fractional shortening was better correlated with the disease progression than endocardial LVEF in patients with ventricular hypertrophy [10, 21].

Limitations

First, LS was only measured in the 4-chamber view in our study. However, the study was mainly intended as a proof of concept study focusing on comparing two different methods for obtaining deformation metrics. Further studies deriving LS in the 4-, 2-, and 3-chamber views are needed to further validate these results. Second, we only compared the values of manual-LS with those of software-LS obtained from one vendor independent software. Previous studies, however, have shown that the vendor-independent software based analysis of LS correlates well with other vendor-specific software based analysis software [7].

Conclusions

Manually deriving LS measures is a reliable and reproducible method for assessing longitudinal deformation in patients with HCM, DCM and healthy subjects. In addition, manual-LS could serve as an additional internal quality control for software derived measures, an important feature recommended in the most recent consensus document on strain imaging [3]. In contrast to the post-processing software analysis, however, manual-LS does not allow comprehensive segmental or strain rate analysis.

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Compliance with ethical standards

Conflict of interest None.

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